COMPARATIVE ANALYSIS OF CROSS SATURATION PHENOMENON IN THE SYNCHRONOUS RELUCTANCE MACHINE OF A 6 AND 3 PHASE WINDING

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Keywords: SynRM, Multiphase, Cross saturation effect, Finite Element Method

Abstract

The paper deals with research on the direct and quadrature axis cross saturation effect in the synchronous reluctance machine (SynRM). The comparative analysis between performance of the 4-pole SynRM of 3-phase and 6-phase windings have been conducted exploiting developed 2D finite element models. In the numerical models of studied machines, the locked rotor method was adopted in which the direct and quadrature axes currents I_q I_d were forced to determine magnetic fluxes in the *d q* axes, respectively. Determined magnetic flux maps have been used next to determine simple analytical model taking into account the cross saturation effect. The quality of proposed analytical description of cross saturation phenomena has been evaluated by comparison to the results of simulations in order to assess the possibility of adapting this description in the control algorithms of SynRM drives.

1 Introduction

In this paper, an attempt has been made to analyse the cross saturation phenomena in a SynRM of three winding variants, the machines of a) 6 phase double layer, b) 3 phase single layer and c) 3 phase double layer windings have been studied. The locked rotor method employing developed numerical field-circuit models of studied machines allowed to the determine the magnetic fluxes in the *d q* axes taking into account the changes and effects of I_d I_q currents. Interpretation of the results as well as the determination of analytical model of the cross saturation effect (CSE) have been carried out using Matlab environment. The effectiveness of the proposed analytical description of the CSE was evaluated in the context of their future application in control algorithms of SynRM.

2 Cross saturation phenomena

In the commonly used control algorithms of electrical machines the magnetic coupling between direct and quadrature axes, i.e. the influence of the cross saturation phenomenon is neglected. In many cases neglecting this crosstalk is justified in the steady state operation conditions of not saturated machines [1], [2]. However, under dynamic operating conditions, the currents in the *d q* axes, and thus the magnetic fluxes, also changes dynamically. These changes taking, into account the nonlinearity and complex geometry of the magnetic circuit, cause the deterioration of the quality of machine control algorithm [3]. To consider the CSE in SynRM the inductances L_d and L_q in the equivalent circuit model of SynRM machine must include the mutual inductance L_{qd} component – see Fig. 1.

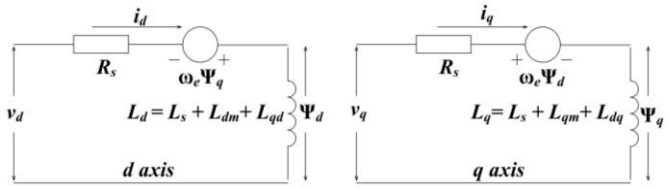

Fig. 1. Equivalent circuit model of SynRM including CSE

In the proposed approach the inductances L_{dm}, L_{qm}, and L_{qd} are nonlinear functions of I_d I_q calculated on the basis of the magnetic field distribution determined by the developed numerical models. Three SynRMs of the same core geometry and different windings has been studied – see Fig. 2.

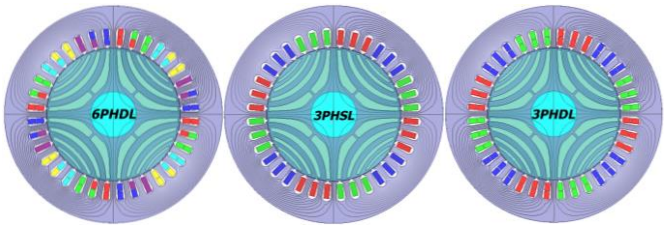

Fig. 2. Considered SynRMs: a) *6PHDL*, b) *3PHSL*, c) *3PHDL*

In order to distinguish between the studied variants, the following nomenclature was adopted. Six-phase double layered - *6PHDL*, Three-phase single layered - *3PHSL*, Three-phase double layered - *3PHDL*. Determined dependences of direct Ψ_d and quadrature Ψ_q fluxes and on changes of the I_d I_q currents for *6PHDL* have been illustrated as 3D plots shown in Fig. 3. It can be observed that the greatest flux changes $\Psi_d = f(I_d)$ caused by the current I_q occur at the area of saturation of the magnetic circuit. It follows that the saturated *d* axis circuit is most susceptible to the influence of Ψ_q flux.

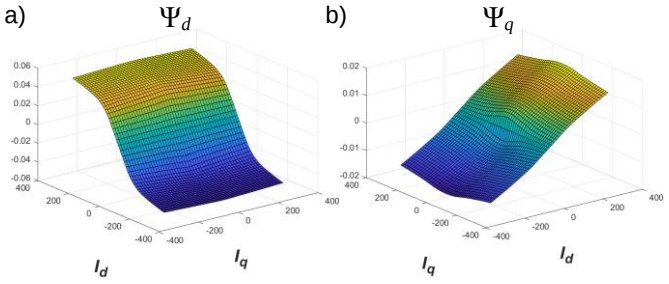

Fig. 3. Magnetic flux as a function of currents I_d I_q; a) Ψ_d, *b)* Ψ_q.

3 Comparison of cross saturation effect

The maximum operating current of the machine is assumed to 300 A. By interpreting obtained results in two-dimensional plots at maximum I_d I_q currents, the exact the influence of the *d q* axis currents can be observed.

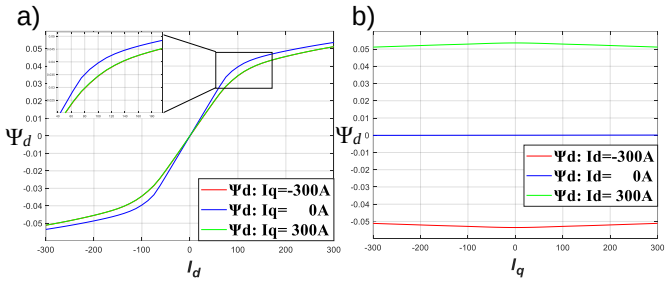

Fig. 4. Influence of I_q and I_d currents on magnetic flux (6PHDL): a) Ψ_d, b) Ψ_q.

It can be observed that impact of I_q on direct axis flux is symmetrical. Regardless of whether the current I_q is positive or negative, it always reduces the flux Ψ_d. Bearing in mind the above considerations, the CSE of studied SynRM machines can be compared.

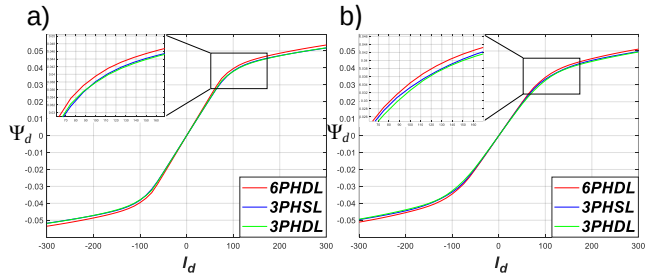

Fig. 5. Comparison of the influence of the I_q current on the Ψ_d flux of studied machines a) I_q=0A b) I_q=300/-300A.

It can be stated that the CSE depends mainly on the geometry and magnetic properties of the magnetic circuit. Based on Fig. 5, it can be observed that the arrangement the 3-phase winding does not affect the distribution of the flux, i.e. practically there are no differences between single and double layer windings. However it should be noted that, a change in the number of phases, and thus a change in the field distribution in the machine, slightly increases the Ψ_d in the saturation area.

4 Analytical model of the CSE

Basing on obtained results of finite element analysis the attempt to formulate simple analytical model of CSE was considered. At the beginning, the base function of the flux Ψ_{d0} = *f(I_d)* for I_q =0 was approximated. The *tgh* and the 3rd order approximation by sine functions have been considered. Next the impact of I_q current was taken into account by calculating the coefficient $k\Psi_{d(Id,Iq)}$ expressed by 1. Finally expression 2 has been proposed to express the interacting currents I_d I_q.

$$k\Psi_{d(Id,Iq)} = \frac{\Psi_{d(Id,Iq)} - \Psi_{d0(Id)}}{\Psi_{d0(Id)}|I_q|} \quad (1)$$

$$\Psi_{d(Id,Iq)} = \Psi_{d0(Id)}\left(1 + k\Psi_{d(Id,Iq)}|I_q|\right) \quad (2)$$

where: $\Psi_{d(Id,Iq)}$ – main function, $\Psi_{d0(Id)}$ – function for I_q=0, $k\Psi_{d(Id,Iq)}$ – flux coefficient.

Analogue approach has been adopted to model the flux in quadrature axis Ψ_q. Because of limited computational resources of digital signal processors used in control systems of SynRM presented above considerations are an introduction to further research on the optimization and reduction of calculation time of model to enable it applicability in control algorithms of SynRM.

5 Conclusions

The paper deals with analysis of the phenomenon of cross saturation in SynRM of different number of phases and winding layers. Obtained, by means of the locked rotor method, results shown that number of winding layers does not have impact on CSE, while the impact of number of phases is remarkable. The simple analytical model was proposed to be implementable in the control algorithms of SynRM.

The detailed description of the developed analytical model as well as results of analysis of the CSE by the alternative the low slip method (taking into account rotor motion) will be discussed during the conference and included the scope of the full version of the paper.

References

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